



SOUTH AFRICA'S TECHNOLOGY SECTOR

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PREFACE

This report provides key findings regarding South Africa's current science and technology (S&T) capabilities. Specifically, the report examines South Africa's stated S&T strategy, leading research centers, defense-related research and development (R&D), and technology transfer controls. Sources for this report include the Web sites of South African government agencies, official governmental white papers, the Lexis–Nexis news service and other proprietary databases, and analyses from several *Jane's* publications and the RAND Corporation.

For the purposes of this report, S&T is defined as all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in physical, engineering, environmental, and life sciences, and the systematic expansion and application of scientific knowledge to develop useful materials, devices, systems, and methods. R&D includes research in the fields of science and technology, combined with evaluation of integrated technologies, representative modes, and prototype systems in a high-fidelity and realistic operating environment, and with the associated engineering and manufacturing development tasks necessary for production.

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KEY FINDINGS

- South Africa's government is upgrading its research and development program (R&D), according to priorities outlined in the National Research and Development Strategy (NRDS) released in 2002. The NRDS emphasizes innovation, human resources, and governance.
- The most important challenge facing South Africa's research establishment is the lack of funding. In 2004–5 gross expenditure on research and development (GERD) was only 0.87 percent of gross domestic product (GDP), well below the 2.26 percent the Organisation for Economic Co-operation and Development (OECD) countries reported in 2004. The South African government's target is a GERD of 1 percent by 2008–9.
- South Africa seeks to emulate South Korea's model of scientific innovation, emphasizing emerging technologies such as biotechnology, nanotechnology, and information technology. However, in 2006 a RAND study classified South Africa as "scientifically developing," the third of four categories used to describe whether a country will be ready by 2020 to adopt 16 selected emerging technology applications.
- South Africa has taken important steps in science and technology (S&T) governance and coordination, establishing a Department of Science and Technology in 2004 and a Space Agency in 2006. South Africa's space program provides satellite launch support to the Russian Federation. Its top goal is the development of a second Sunsat imagery satellite.
- South Africa's defense spending plunged following the abolition of apartheid, causing hardship to the country's defense industry, including a sharp reduction in defense employment. However, in 2006 the figure for defense spending, at that time 1.7 percent of GDP, began to rise.
- South Africa's leading defense manufacturer, Denel, which has divisions in aerospace and land systems, experienced a severe decline in its financial performance but averted bankruptcy with the financial assistance of the South African government. In 2005 the Stockholm International Peace Research Institute removed Denel from the list of the world's largest arms-producing companies.
- In 2006 South Africa was the world's ninth largest arms importer and sixteenth largest arms exporter. One of South Africa's most important arms acquisitions involves three German Type 209/1400M diesel attack submarines ordered in 2000. South Africa

observes relatively strict arms export controls, according to the terms of the National Conventional Arms Control Act of 2002. However, Amnesty International has objected to the 2005–6 sale of armored vehicles to Uganda and Indonesia, where these vehicles were used to commit human rights violations. South Africa abandoned the development of weapons of mass destruction and related delivery systems in 1993.

- The retirement and emigration of South African scientists and engineers, many of them veterans of the country's struggling defense sector, may pose some of the same dangers as the displacement of Soviet defense workers after the collapse of the Soviet Union. Denel's perilous financial condition could make the company vulnerable to the temptation to sell arms to unscrupulous parties around the world.
- South Africa has noteworthy capabilities in the conversion of coal to liquid fuel, pebble bed nuclear reactor technology, and astronomy. The country's future development of its expertise in astronomy depends on whether South Africa is selected to host the proposed Square Kilometre Array radio telescope. Pebble bed nuclear technology is in the planning stage but not yet in production in South Africa. Perhaps most important, South Africa's expertise in synthetic fuels, including proprietary adaptations of Fischer-Tropsch technology for coal-to-liquid fuel conversion, may attract the notice of any country seeking technologies to enhance its energy security.

OVERVIEW OF SOUTH AFRICA'S S&T RESEARCH

The abolition of the apartheid system in 1990–91, followed by the first free elections in 1994, caused a change of emphasis and diminished activity in South Africa's S&T sector. In recent years, South Africa has begun to rebuild its research program. During the apartheid era, the government emphasized military research, including nuclear weapons programs and energy self-sufficiency, especially coal-to-liquid fuel conversion.¹ The new government phased out the nuclear weapons program, while development of coal-to-liquid fuel conversion continues in the private sector. The postapartheid government has maintained research programs in manufacturing, agriculture, mining and minerals, and basic science.²

During the transition from the apartheid system, South Africa's share of global scientific output, as measured by one of the common yardsticks, publication activity, declined from 0.8 percent in 1990 to 0.49 percent in 2000.³ However, South Africa's poor publication record is just one of the indicators of the disparity between its actual scientific achievement and its aspirations. According to a South African government assessment in 2002, "the total capacity of the [S&T] system is about one-third to one-half the size that it should be to form the basis of a competitive knowledge-based economy for South Africa in the medium to long term."⁴

Challenges Facing South Africa's S&T Sector

South Africa's S&T sector needs to overcome several challenges, the most critical being the following:

- **Inadequate R&D funding, including private-sector disinvestment**⁵—In 2004–5 R&D funding constituted only 0.87 percent of gross domestic product (GDP). Spending on basic research was also low (0.16 percent of GDP) by international standards.⁶ In 2002

¹ Republic of South Africa, Department of Science and Technology, "South Africa's National Research and Development Strategy" (report, Pretoria, DS&T, August 2002), 40, http://www.dst.gov.za/publications/reports/sa_nat_rd_strat.pdf.

² Republic of South Africa, "National Research and Development Strategy," 19.

³ Jerome A. Singh, "Ten-year Review of Research in South Africa," *Nature*, April 29, 2004, 891, http://www.pisavisionlab.org/downloads/Nature_BrainDrain.pdf.

⁴ Republic of South Africa, "National Research and Development Strategy," 40.

⁵ Republic of South Africa, "National Research and Development Strategy," 19.

⁶ Republic of South Africa, Department of Science and Technology, *National Survey of Research and Experimental Development (R&D) (2004/05 Fiscal Year)* (report, Pretoria, DS&T, June 22, 2006), 28–29, <http://www.dst.gov.za/publications/r&dsurveys.php>.

the South African government found that, with the exception of the energy firm Sasol and some small innovative firms, most of the private sector in South Africa was investing less in R&D.⁷

- **Inadequate expertise in critical technologies**—South Africa lacks expert researchers, particularly in technologies critical to its science and technology sector, such as biotechnology and information and communications technology (ICT).⁸
- **Inadequate or untapped human talent**⁹—South Africa's number of researchers per 1,000 employees (1.6) is relatively low by international standards.¹⁰ By contrast, Australia and South Korea, two countries that South Africa aspires to emulate, have 7.8 and 6.8 researchers per 1,000 employees, respectively.¹¹ According to the South African government, the existing scientific and engineering workforce is aging and lacks racial and gender balance. The brain drain of scientists and engineers through retirement and emigration has not yet stimulated development of more diverse replacement talent.¹²
- **A fragmented and chaotic system of S&T governance**—Only in 2004 did the government establish a Department of Science and Technology. Although this was a significant step in the right direction, it did not solve all the problems regarding lines of authority in the S&T sector.¹³

The country also must overcome the following weaknesses:

- **Low patent production**—South Africa generates only about 2.5 patents per million population per year, as compared to about 645 per million in the United States;¹⁴
- **Inadequate international impact of South African research journals**—In 2006 South Africa had 255 accredited research journals, but about half had almost no impact abroad,

⁷ Republic of South Africa, "National Research and Development Strategy," 19.

⁸ Republic of South Africa, "National Research and Development Strategy," 38.

⁹ Organisation for Economic Co-operation and Development, "Science, Technology and Industry Outlook 2004, Country Response to Policy Questionnaire" (questionnaire, Paris, OECD, January 6, 2005), 2, <http://www.oecd.org/dataoecd/30/9/34243230.pdf>.

¹⁰ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 14.

¹¹ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 15.

¹² Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 15; Republic of South Africa, "National Research and Development Strategy," 21, 51, 54; OECD, "Science, Technology and Industry Outlook 2004," 2.

¹³ Republic of South Africa, "National Research and Development Strategy," 22, 61–62; OECD, "Science, Technology and Industry Outlook 2004," 3.

with less than one-tenth indexed on international citation lists.¹⁵ According to *Science* magazine, critics attribute the weakness of the journals to the government's policy of subsidizing universities based on the number of journals.¹⁶

South African journals had a below-average impact (percentage of citations vs. the world average) in all 21 categories, but performed relatively well in immunology, agricultural sciences, materials science, and social sciences.¹⁷ For South Africa's scientific publication record over a recent five-year period, see Table 1.¹⁸

Table 1. South Africa's World Share of Science and Social Science Papers, 1998–2002		
Field	Percentage of Papers from South Africa	Relative Impact Compared to World
Plant and Animal Science	1.59	–35
Ecology/Environmental	1.16	–25
Geosciences	1.13	–27
Space Science	0.91	–19
Education	0.80	–33
Microbiology	0.64	–25
Social Sciences	0.61	–15
Agricultural Sciences	0.53	–8
South Africa, 1998–2002's overall percentage share, all fields: 0.50		
Psychology/Psychiatry	0.49	–48
Economics and Business	0.47	–73
Clinical Medicine	0.44	–20
Pharmacology	0.44	–30
Immunology	0.43	–1
Mathematics	0.41	–21
Biology and Biochemistry	0.36	–41
Chemistry	0.33	–40
Engineering	0.23	–32
Materials Science	0.30	–15
Molecular Biology	0.28	–48
Physics	0.26	–20
Computer Science	0.19	–46
Neurosciences	0.19	–46
Source: "Science in South Africa, 1998–2002," <i>SCI-BYTES</i> , September 29, 2003, http://www.in-cites.com/research/2003/september_29_2003-2.html .		

¹⁴ Republic of South Africa, "National Research and Development Strategy," 67; World Intellectual Property Organization, "WIPO Patent Report: Statistics on Worldwide Patent Activity" (report, Geneva, WIPO, 2006), http://www.wipo.int/ipstats/en/statistics/patents/patent_report_2006.html#P93_7755.

¹⁵ Robert Koenig, "A Call to Improve South Africa's Journals," *Science*, May 12, 2006, 831.

¹⁶ Koenig, 831.

¹⁷ "Science in South Africa, 1998–2002," *SCI-BYTES*, September 29, 2003, http://www.in-cites.com/research/2003/september_29_2003-2.html.

¹⁸ "Science in South Africa, 1998–2002."

R&D Funding

Amount of Funding

Perhaps the most important deficiency facing South Africa's S&T establishment is the lack of funding. Corresponding to the downward trend in South Africa's scientific output, R&D spending declined from 1991 to 1997 before beginning to rise again. However, South Africa has used two methods of measuring spending during this period, making it difficult to interpret its results. The first measure, based on apartheid-era conventions, indicates that gross expenditure on research and development as a percentage of GDP (GERD/GDP) peaked at about 1.1 percent in 1991 and declined to a low of 0.60 percent in 1997.¹⁹ However, a revised formula discounts abandoned initiatives and tracks spending on a more apples-to-apples basis, showing a gentler decline of GERD/GDP from slightly more than 0.80 percent in 1991 to 0.60 percent in 1997. After the trough in 1997, R&D spending rose to a record (on the revised basis) of 0.87 percent in 2004–5.²⁰ However, the 0.87 percent (US\$1.74 billion) achieved in 2004–5 still fell short of the government's target of 1 percent by 2008–9.²¹ This target, in turn, is well below the actual GERD/GDP of 2.26 percent achieved by the 30 members of the OECD in 2004.²²

Composition of Funding

In order to understand the direction of South Africa's R&D program, it is necessary to examine not only the level of funding but also its composition. Composition can be measured by funding source, by performance or impact, and by sector or application. In a speech in May 2007, South African President Thabo Mbeki reported that South Africa was reviewing an OECD report evaluating South Africa's R&D policies. According to this report, "the business sector funds 45 percent of formal R&D and performs 58 percent of it."²³ Therefore, the OECD recommended that the private sector be given a larger role in shaping innovation policy and

¹⁹ Republic of South Africa, "National Survey of Research and Experimental Development (R&D)," 11.

²⁰ Republic of South Africa, "National Survey of Research and Experimental Development (R&D)," 10.

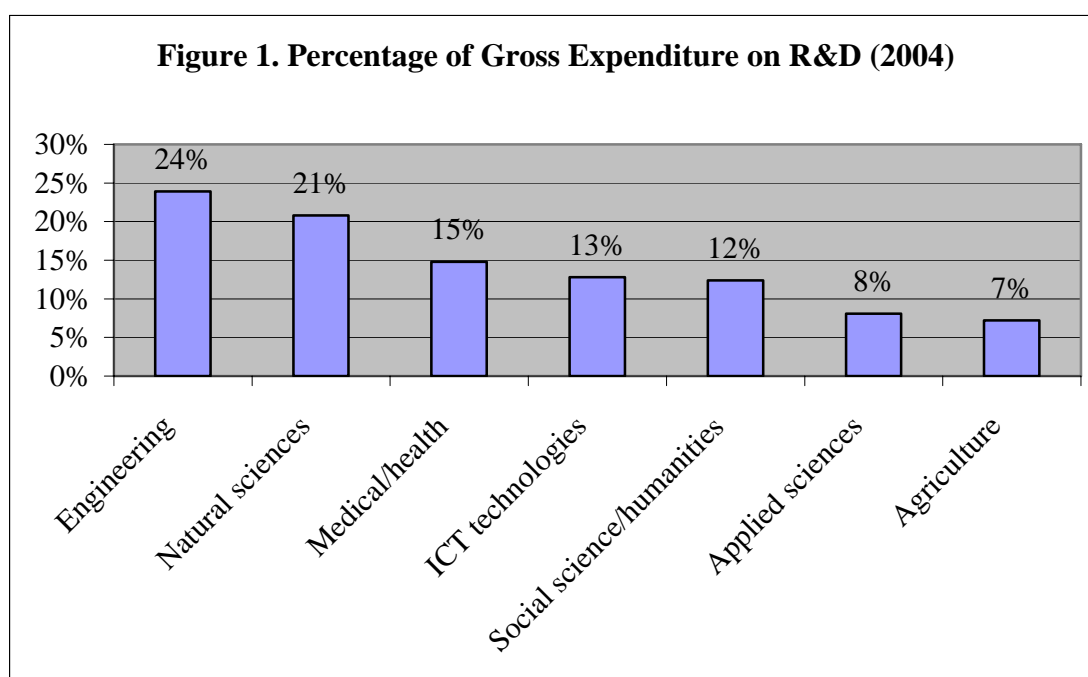
²¹ Republic of South Africa, Department of Science and Technology, "Annual Report, 2005/06" (report, Pretoria, DS&T, 2006), 2, 67, http://www.dst.gov.za/publications/annual_report.php; "National Survey of Research and Experimental Development (R&D)," 2.

²² Republic of South Africa, "National Survey of Research and Experimental Development (R&D)," 13.

²³ Thabo Mbeki, "We Must Develop Science and Technology," *Africa News*, May 4, 2007, <http://www.nexis.com>.

endorsed a planned tax incentive to encourage small-to-medium-sized enterprises and multinational corporations to invest in R&D.²⁴

According to official statistics from the Department of Science and Technology, in 2004 business funded 56.3 percent of R&D performance, followed by higher education funding of 21.1 percent, government funding of 20.9 percent, and the not-for-profit sector funding of 1.7 percent.²⁵ Also in 2004, the leading targets of R&D spending were the fields of engineering, natural sciences, and medicine and health sciences. R&D spending was divided among various fields as shown below (see Figure 1):²⁶



Source: Republic of South Africa, Department of Science and Technology, *National Survey of Research and Experimental Development (R&D) (2004/05 Fiscal Year)* (report, Pretoria: DS&T, June 22, 2006), 25, <http://www.dst.gov.za/publications/r&dsurveys.php>.

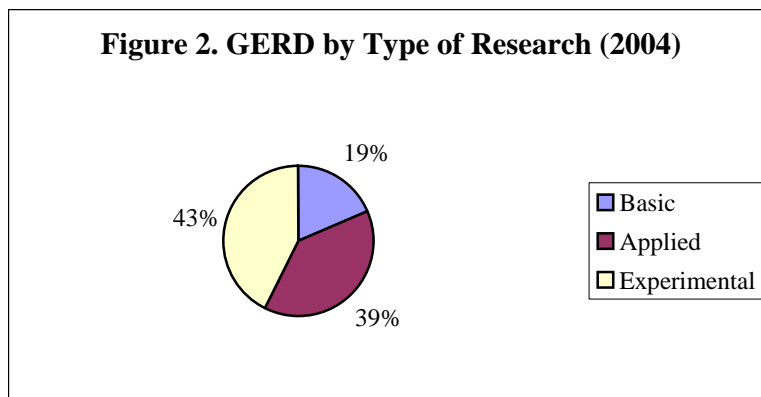
In 2004 figures for GERD, according to type of research, indicated that experimental development, mainly funded by business, accounted for the largest share of GERD at 43 percent. Improved survey coverage of clinical trials and services accounted for the size of this category. Applied research was a close second, followed by a relatively modest share for basic research

²⁴ Mbeki.

²⁵ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 21.

²⁶ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 25.

(see Figure 2).²⁷ In 2004 South Africa spent 0.16 percent of GDP on basic research, much less than France's 0.53 percent and the 0.50 percent spent by the United States.²⁸



Source: Republic of South Africa, Department of Science and Technology, *National Survey of Research and Experimental Development (R&D) (2004/05 Fiscal Year)* (report, Pretoria: DS&T, June 22, 2006), 29, <http://www.dst.gov.za/publications/r&dsurveys.php>.

Major Research Centers

South Africa's geography gives it an advantage in astronomy, human paleontology, biodiversity, and Antarctic research. In addition, South Africa has a comparative advantage in fields such as deep mining, HIV/AIDS vaccine development, encryption technology, microsatellite engineering, and fluorine technology. Fluorine technology employs industrial chemical applications requiring expertise transferred from South Africa's discontinued uranium enrichment program.²⁹ South Africa's research in microsatellite technology includes a successor to the 64-kg Sunsat remote sensing and packet communications microsatellite built at the University of Stellenbosch in 1999. A diverse range of major research centers reflects South Africa's comparative advantage in these scientific fields.

²⁷ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 26–27.

²⁸ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 29.

²⁹ Republic of South Africa, "National Research and Development Strategy," 54; South African National Research Foundation, "Space in South Africa," South African Space Portal, <http://www.space.gov.za/spaceinza/index.php> (accessed July 25, 2007).

The Council for Scientific and Industrial Research (CSIR)

The Council for Scientific and Industrial Research (CSIR), South Africa's most broad-based science council, receives 40 percent of its funding from the Department of Science and Technology, with the remainder coming from government and private-sector contracts and intellectual property royalties.³⁰ CSIR conducts multidisciplinary research with an emphasis on promoting innovation and South Africa's economic and technological competitiveness.³¹ Its areas of expertise and the specific focus in each discipline are as follows:

- **Biosciences**—With a focus on drug and therapeutic discovery; bio-processing; product development
- **Built environment**—With a focus on architectural sciences; construction; infrastructure engineering, systems, and operations; logistics and quantitative methods; planning support systems
- **Defense, peace, safety and security**—With a focus on aeronautic systems (experimental and computational aeromechanics and aero-structural sciences); “landwards sciences” (detonics or firearms and ballistics, protection, and soldier systems); optronic sensor systems (surveillance, countermeasures, and electronic warfare); radar and electronic warfare systems (sensors operating in the microwave spectrum); safety and security (crime prevention and cyber security); systems modeling; technology for special operations
- **Information and communications technology**—With a focus on computer literacy; earth observation; human interaction with machines; open source software; wireless technology for Africa
- **Laser technology**—With a focus on biophotonics (light-activated bio-nanodevices and low-level laser therapy); laser material processing (profile cutting, cladding, hardening, laser ablation, and welding); laser physics and technology (diode pumped solid state lasers, femtosecond laser systems, laser beam propagation and beam forming); laser spectroscopy (differential absorption for the remote detection of gasses, Raman spectroscopy, and laser induced plasma spectroscopy)

³⁰ Republic of South Africa, Council for Scientific and Industrial Research (CSIR), March 14, 2007, <http://www.csir.co.za>.

³¹ Republic of South Africa, Council for Scientific and Industrial Research (CSIR).

- **Materials science and manufacturing**—With a focus on emerging science initiatives (aerospace, metal initiatives, nanomaterials and nanostructures); energy and processes (clean coal and other industrial processes, fuel cells, and renewables); fibers and textiles (non-woven products); manufacturing S&T (digital and micro-manufacturing, advanced robotics and manufacturing); metals and metal processes (fundamental properties and modeling, improving primary metal production processes, alloying and processing, and engineering design and analysis methods); polymers and bioceramics (smart materials for drug delivery and tissue engineering, advanced industrial polymers and composites); sensor science and technology (smart structures, electrooptic sensing and imaging, and sonar)
- **Natural resources and the environment**—With a focus on ecosystems; forestry; mining; pollution and waste; resource-based sustainable development; water resources
- **Space technology**—With a focus on the collection of satellite imagery for earth observation; tracking; telemetry; command for satellite life cycle; mission support³²

Nuclear Energy Corporation of South Africa

The Nuclear Energy Corporation of South Africa (NЕСSA), a state-owned company, conducts R&D in the area of nuclear energy,³³ operating a research reactor called SAFARI-1 in Pelindaba, west of Pretoria, and a radioactive waste-disposal facility in Vaalputs, a remote area in the Northern Cape. Once the core of South Africa's discontinued nuclear weapons program, SAFARI-1 is a 20 MW tank-in-pool type research reactor subject to international controls. SAFARI-1 is used for commercial purposes³⁴ to produce radiochemicals such as molybdenum-99, iodine-131, phosphorus-32, and sulfur-35 for medical and agricultural uses. It is also used for neutron and gamma irradiation.³⁵ At the waste-disposal facility, low- and intermediate-nuclear waste is not dumped but rather buried in sealed drums that are subject to retrieval.³⁶

³² Republic of South Africa, Council for Scientific and Industrial Research (CSIR).

³³ Republic of South Africa, Nuclear Energy Corporation of South Africa (NЕСSA), "NЕСSA at the Cutting Edge of Nuclear Technology," NЕСSA, 2007, <http://www.necsa.co.za/>.

³⁴ "Pelindaba Nuclear Research Center," Global Security.org, April 28, 2005, <http://www.globalsecurity.org/wmd/world/rsa/pelindaba.htm>.

³⁵ Republic of South Africa, Nuclear Energy Corporation of South Africa (NЕСSA), "The Nuclear Technology Products Division," NЕСSA, 2007, <http://www.necsa.co.za/>.

³⁶ Kelvin Klemm, "Vaalputs Nuclear Waste Repository Staff Doing SA Proud," *Creamer Media's Engineering News*, December 15, 2006, http://www.engineeringnews.co.za/article.php?a_id=98872.

South Africa has expertise in innovative pebble bed nuclear reactor technology, although construction of a reactor using this technology is only in the planning stage. President Mbeki favors using both conventional and pebble bed technologies to enhance South Africa's currently modest nuclear power generating capacity.³⁷ Pebble bed design reactors use a different type of uranium fuel than conventional reactors. In contrast to conventional reactor fuel, which consists of "uranium pellets embedded in metal rods and bathed in cooling water," the pebble bed reactor's fuel consists of uranium kernels "encased in billiard-ball-sized graphite pebbles filling a doughnut-shaped reactor core lined with graphite."³⁸ The graphite "moderates" the nuclear reaction, which, according to the advocates of pebble bed design, has significant benefits for both safety and thermal efficiency.³⁹

NESCA supports Mbeki's plans to expand South Africa's capacity to generate electricity from nuclear power. Currently, South Africa's nuclear power-based, electricity-generating capacity is limited to a single 1,800 MW nuclear power station in Koeberg near Cape Town. However, in June 2007, NESCA announced that it expects nuclear power to produce 15,000 MW by 2025 and 25,000 MW by 2030.⁴⁰ NESCA is considering the use of pebble bed design to accomplish this objective. South African officials propose building South Africa's first pebble bed modular reactor at the same site in Koeberg as the existing conventional nuclear reactor, and one minister suggests that up to 24 such reactors eventually could be built throughout the country.⁴¹ South Africa hopes that its growing expertise in pebble bed technology could make it a major player in the international nuclear power industry.

Southern African Large Telescope and the Proposed Square Kilometre Array

South Africa hopes to build on its niche competence in astronomy using its geographic advantage of clear, dark skies.⁴² Currently, South Africa is home to the largest single optical telescope in the Southern hemisphere, the Southern African Large Telescope (SALT), featuring a

³⁷ Keith Campbell, "SA's Reliance on Nuclear Energy Set to Increase," Republic of South Africa, Pebble Bed Modular Reactor (PBMR), March 9, 2007, <http://www.pbmr.co.za/>.

³⁸ David Talbott, "The Next Nuclear Plant," *Technology Review*, January–February 2002, 56.

³⁹ Talbott, "The Next Nuclear Plant."

⁴⁰ Judith Perera, "South Africa Foresees Massive Expansion," Republic of South Africa, Pebble Bed Modular Reactor (PBMR), March 5, 2007, <http://www.pbmr.co.za/>.

⁴¹ Sven Lunsche, "Getting Clean," *Financial Mail* [Johannesburg], June 22, 2007, <http://secure.financialmail.co.za/07/0622/cover/coverstoryd.htm>.

⁴² OECD, "Science, Technology and Industry Outlook 2004," 5–6.

hexagonal mirror array 11 meters wide. An international consortium, including Germany, New Zealand, Poland, South Africa, the United Kingdom, and the United States, completed the construction of this telescope in November 2005.⁴³ The South African Astronomical Observatory, a national research facility, is responsible for managing SALT.⁴⁴

Ideally, South Africa's next step toward its goal would be selection by an international consortium to host the next-generation Square Kilometre Array (SKA) radio telescope. South Africa is one of two countries remaining on a short list to host the SKA; the other contender is Australia.⁴⁵ The International Square Kilometer Array Steering Committee, a consortium of eight institutions from six countries—Australia, Canada, China, India, the Netherlands, and the United States—is expected to name the winner in 2010.⁴⁶ Construction, which would cost an estimated US\$2 billion, would begin in 2014.⁴⁷ The SKA would consist of thousands of dishes, each 10–15 meters in diameter, spread over 1 million square meters. At the core of the array would be a radio fish eye lens.⁴⁸ The SKA would enable many simultaneous independent observations. It could help scientists answer fundamental questions about the age and origin of the universe, support the study of dark energy and matter, and possibly detect life elsewhere in the universe.⁴⁹

Sasol Ltd.

Sasol Ltd., South Africa's leading energy company, has global operations in oil, gas, and chemical exploration and production.⁵⁰ Privatized in 1979, Sasol is best known for its expertise in synthetic fuels. In fact, Sasol is the world's largest coal liquefaction producer, with a capacity of 150,000 barrels per day.⁵¹ Sasol has developed two proprietary adaptations of Fischer-Tropsch technology for synthetic fuel production:

⁴³ Republic of South Africa, SALT, 2007, <http://www.salt.ac.za/>.

⁴⁴ Republic of South Africa, National Research Foundation (NRF), "South African Astronomical Observatory" (NRF Business Plan 2007/08–2009/10), <http://www.nrf.ac.za/profile/nrffbusinessplan.pdf>.

⁴⁵ Republic of South Africa, Square Kilometre Array (SKA) South Africa, "About the SKA," SKA, 2007, <http://www.ska.ac.za/aboutska/index.shtml>.

⁴⁶ Republic of South Africa, Square Kilometre Array (SKA) South Africa, "International Organization," SKA, 2007, <http://www.skatelescope.org/>.

⁴⁷ Republic of South Africa, "About the SKA."

⁴⁸ Republic of South Africa, "About the SKA."

⁴⁹ Republic of South Africa, "About the SKA."

⁵⁰ "Sasol Facts," Sasol, 2007, http://www.sasol.com/sasol_internet/downloads/sasolfacts_2007_1180093894888.pdf.

⁵¹ United States, Department of Energy (DoE), "South Africa Country Analysis Brief," DoE, January 2005, <http://www.eia.doe.gov/emeu/cabs/safrica.html>.

- The high-temperature Sasol Advanced Synthol process converts synthesis feed gas from coal into gasoline and light olefins.
- The low-temperature Sasol Slurry Phase Distillate process converts natural gas first into synthetic gas and then into high-quality diesel.⁵²

However, despite Sasol's and, by extension, South Africa's expertise in synthetic fuels, the country imports the majority of its crude oil from the Middle East.⁵³

National Research and Development Strategy

In August 2002, the government released a National Research and Development Strategy (NRDS) aimed at putting South African science on a productive path. The NRDS represents an overarching research framework based on the experiences of Australia, Malaysia, and South Korea, countries that South Africa considers as peers.⁵⁴ According to South Africa's analysis, Australia's R&D strategy is to add value to its resource-based economy; Malaysia pursues a "fast follower" strategy, importing expertise through foreign direct investment; and South Korea promotes industrial innovation, emphasizing advanced manufacturing, IT, and biotechnology. South Korea's strategy also emphasizes "high levels of educational and post-graduate research and patent spending."⁵⁵

Of these three R&D models, South Africa decided in favor of following South Korea's knowledge-intensive strategy.⁵⁶ In keeping with this decision, the NRDS emphasizes innovation, human resources, and governance.⁵⁷ Government spending on nanotechnology of US\$64 million over a three-year period, beginning in the 2006–7 fiscal year, will fund capacity building, research and innovation networks, flagship projects, and characterization centers in the following six areas:

- advanced materials and manufacturing
- chemical- and bio-processing
- energy

⁵² "Explore Sasol: Technologies & Processes," Sasol, May 3, 2007, <http://www.sasol.com>.

⁵³ U.S., DoE, "South Africa Country Analysis Brief."

⁵⁴ Republic of South Africa, "National Research and Development Strategy," 29.

⁵⁵ Republic of South Africa, "National Research and Development Strategy," 29.

⁵⁶ Republic of South Africa, "National Research and Development Strategy," 29.

⁵⁷ Republic of South Africa, "National Research and Development Strategy," 23–24.

- health
- mining and minerals
- water⁵⁸

Innovation

An innovation chasm between basic and applied research prevents South Africa from converting basic research into consumer products and services.⁵⁹ The NRDS emphasizes innovative scientific research and product development in manufacturing, natural resources, and especially in recently emerging fields, such as biotechnology, ICT, and nanotechnology.⁶⁰ South Africa is committed to rectifying its currently limited capacity in these latter three fields.

Biotechnology

In biotechnology, most of South Africa's successes have been in first-generation applications, namely the use of selected biological organisms for agricultural production. South Africa has achieved limited success in a second-generation application, using pure cell or tissue cultures to yield new products, such as lysine for animal feed and vaccines for both animals and humans.⁶¹ South Africa hopes to move into more lucrative third-generation biotechnology, using recombinant DNA to produce biopharmaceuticals. So far it has not had much success in this area. At the same time, South Africa intends to continue to emphasize research in genetic modification of crops such as corn and cotton.⁶²

⁵⁸ "National Nanotechnology Strategy," 13.

⁵⁹ OECD, "Science, Technology and Industry Outlook 2004," 1.

⁶⁰ Republic of South Africa, Department of Science and Technology, "National Nanotechnology Strategy" (report, Pretoria, DS&T, August 18, 2006), <http://www.dst.gov.za/publications/reports/Nanotech.pdf>.

⁶¹ Republic of South Africa, Department of Science and Technology, "National Biotechnology Strategy for South Africa," (report, Pretoria, DS&T, June 2001), 16–17, http://www.dst.gov.za/publications/reports/dst_biotechnology_strategy.PDF.

⁶² Republic of South Africa, "National Biotechnology Strategy," 19.

Advanced Manufacturing Technology/ICT

South Africa's strategy for research in advanced manufacturing technology focuses on applying innovative methods to a number of industry sectors.⁶³ Innovative methods are in development in the areas of advanced materials; cleaner production; ICT in manufacturing; logistics; product and production technologies; small-to-medium-size enterprise development; and standards, quality, accreditation, and metrology (SQAM). According to South Africa's National Advisory Council on Innovation (NACI), each of the newly developed methods can be used, at least in theory, in a wide variety of industry sectors, including aerospace; automotive and transport; capital goods; chemicals; clothing and textiles; cultural and craft; and metals and minerals. From among all of the possible uses in industry, NACI identified areas in which innovative methods may be applied in specific industries, with a high potential for resulting value. The four areas of industry most likely to benefit from the use of innovative methods are advanced materials, advanced metals, ICT in manufacturing innovation, and national craft development.⁶⁴

Nanotechnology

In 2006 the Ministry of Science and Technology announced South Africa's new National Nanotechnology Strategy. According to this strategy, South Africa is dedicated to using nanotechnology to stimulate not only industrial growth, but also social development.⁶⁵ Even before announcing the strategy, South Africa was using nanotechnology in development of socially responsible technologies, such as solar cells and fuel cells for renewable energy and nanomembranes for water purification systems designed to prevent the spread of cholera and typhoid in the interest of public health. South Africa seeks to build on these successes, with an emphasis on encouraging the conversion of R&D breakthroughs into commercial products.⁶⁶

⁶³ Republic of South Africa, National Advisory Council on Innovation (NACI), "National Advanced Manufacturing Technology Strategy for South Africa" (report, Pretoria, NACI, 2003), 9, http://www.naci.org.za/pdfs/amts_112003.pdf.

⁶⁴ Republic of South Africa, "National Advanced Manufacturing Technology Strategy," 17–18.

⁶⁵ Derek Hanekom, "Keynote Address at the Launch of the South African National Nanotechnology Strategy," April 13, 2006, <http://www.dst.gov.za/media/speeches.php?id=102>.

⁶⁶ "National Nanotechnology Strategy," 13.

Human Resources

NRDS also emphasizes human resources development, attempting to address the erosion and lack of diversity of South Africa's scientific community. South African policymakers openly complain that the country's scientists are predominantly aging, white males and favor measures to develop the untapped resource of black and female scientific talent.⁶⁷ In the meantime, retirement and emigration to other English-speaking countries (United States, Australia, Canada, United Kingdom) are causing rapid attrition among practicing scientists. In 2004 the annual attrition rate among all South African researchers was 11 percent at government laboratories and 15 percent at universities.⁶⁸ South Africa needs to replenish its already modest base of research talent. In 2004 South Africa had only 1.6 researchers per 1,000 employees, compared to 11 per 1,000 in Sweden, 7.8 per 1,000 in France and Australia, and 6.8 per 1,000 in South Korea.⁶⁹

Governance

South Africa's NRDS targets governance, with the goal of effective government management of South Africa's R&D system. In 2004 the government took an important step in this direction, establishing a dedicated Department of Science and Technology (DST), a spin-off from the Department of Arts, Culture, Science and Technology.⁷⁰ One of the DST's main objectives is establishing cohesive, performance-based management of disparate research institutions and funding agencies. The conflict among global crosscutting institutions and various line departments complicates this task. In addition, the DST continues to share with the Department of Education responsibility for basic research.⁷¹

South Africa's four types of scientific research institutions illustrate the complexity of its S&T system:

- State-owned or state-supported institutions such as Denel, defense industry manufacturer; Electricity Supply Commission (Eskom); South African Nuclear Energy Corporation

⁶⁷ OECD, "Science, Technology and Industry Outlook 2004," 9.

⁶⁸ Singh, 891.

⁶⁹ Republic of South Africa, *National Survey of Research and Experimental Development (R&D)*, 15; Republic of South Africa, "National Research and Development Strategy," 7.

⁷⁰ Mbeki.

⁷¹ Republic of South Africa, "National Research and Development Strategy," 17.

(NECSA); Telkom SA Limited, telecommunication provider; Transnet, transportation infrastructure authority; South African Forestry Company Limited (Safcol)

- Science councils such as Mintek, the national mineral research organization; Council for Geoscience; Council for Scientific and Industrial Research (CSIR); South African Bureau of Standards (SABS); Medical Research Council; Agricultural Research Council
- Universities and technical institutes known as *technikons*
- Domain-specific government research organizations⁷²

The confusing authority of board appointments of these entities compounds the complexity of S&T research in South Africa (see Table 2).⁷³

Table 2. Appointment Authority for the Boards of South African Research Institutions	
Institution	Appointment Authority
State-owned Institutions	Various ministers
Science Councils	
Mintek	Minister of Minerals and Energy
Council for Geoscience	Minister of Minerals and Energy
The Council for Scientific and Industrial Research	Minister of Trade and Industry
South African Bureau of Standards	Minister of Trade and Industry
Medical Research Council	Minister of Health
Agricultural Research Council	Minister of Agriculture
Source: Republic of South Africa, "South Africa's National Research and Development Strategy" (report, Pretoria, DS&T, August 2002, http://www.dst.gov.za/publications/reports/sa_nat_rd_strat.pdf).	

Line authority over the following South African institutions is also mixed (see Table 3).⁷⁴

Table 3. Line Authority of South African Research Institutions	
Institution	Line Authority
National Research Foundation	Minister of Science and Technology
Human Sciences Research Council	Minister of Science and Technology
Universities and technikons	Minister of Education
Source: Republic of South Africa, "South Africa's National Research and Development Strategy" (report, Pretoria, DS&T, August 2002, http://www.dst.gov.za/publications/reports/sa_nat_rd_strat.pdf).	

⁷² Republic of South Africa, "National Research and Development Strategy," 61–62.

⁷³ Republic of South Africa, "National Research and Development Strategy," 61.

⁷⁴ Republic of South Africa, "National Research and Development Strategy," 61–62.

South Africa's Space Program

During apartheid, South Africa pursued a space program because of its concern about the security threat posed by Soviet influence in Africa and because it could not rely on support from the United States and Europe.⁷⁵ In the period immediately after the end of apartheid, the country no longer considered space a priority. However, in 2005 South Africa took an important step toward reviving the space program, signing an agreement with the Russian Aviation and Space Agency. Under this agreement, Russia may launch satellites from South Africa.⁷⁶ However, in 2006, four years after the NRDS was promulgated, South Africa created the South African Space Agency, taking a second, more decisive step toward upgrading its space program.⁷⁷ The agency's immediate goal is the development of a second Sunsat satellite with enhanced imagery capabilities.⁷⁸ South Africa would prefer to become independent of the United States and Europe for satellite imaging and to be able to monitor regional instability.⁷⁹

South Africa's International Rank

Despite South Africa's lofty ambitions to further develop its strengths in nanotechnology, biotechnology, and ICT, the country ranks low internationally in scientific capabilities. The RAND Corporation's global study of 2006 classified South Africa as "scientifically developing," ranking third out of four categories in regard to its readiness to adopt 16 future technology applications in the fields of biotechnology, information technology, materials technology, and nanotechnology by 2020.⁸⁰ Brazil, Chile, Colombia, Indonesia, Mexico, and Turkey also ranked third. A country's rank reflects its S&T capacity, economic development, and social

⁷⁵ Chris Alden, "South Africa's Space Programme: Past and Present," *Strategic Review for Southern Africa* 29, no. 1 (May 2007): 1, 39–44.

⁷⁶ "South Africa's Space Programme," 48.

⁷⁷ "South Africa's Space Programme," 47.

⁷⁸ "South Africa's Space Programme," 47.

⁷⁹ "South Africa's Space Programme," 48.

⁸⁰ Richard Silberglitt, Philip S. Antón, David R. Howell, and Anny Wong, "The Global Technology Revolution 2020, In-Depth Analyses—Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications" (technical report, Santa Monica, RAND, 2006), 66, http://www.rand.org/pubs/technical_reports/2006/RAND_TR303.pdf.

development.⁸¹ According to the RAND study, South Africa is prepared to adopt the following technology applications:

- cheap solar energy
- filters and catalysts
- genetically modified crops
- green manufacturing
- hybrid vehicles
- rapid bioassays
- rural wireless communications
- ubiquitous radio frequency identification (RFID) tagging

However, RAND's study found South Africa ill equipped to adopt the following technologies: improved diagnostic and surgical methods, pervasive sensors, quantum cryptography, tissue engineering, ubiquitous information access, and wearable computers.⁸²

South Africa's International Cooperative S&T Agreements

South Africa currently has 35 bilateral S&T agreements, compared with a "handful" in 1994.⁸³ South Africa strengthened its bilateral cooperation with Belgium, France, Germany, Japan, Norway, and the United Kingdom.⁸⁴ Table 4 details these and other selected other cooperative S&T agreements.⁸⁵

⁸¹ Silbergitt, et al, 66.

⁸² Silbergitt, et al, 119.

⁸³ Republic of South Africa, Department of Science and Technology, "Annual Report, 2005/06," 38; "National Research and Development Strategy," 58.

⁸⁴ Republic of South Africa, Department of Science and Technology, "Annual Report, 2005/06," 33.

⁸⁵ Republic of South Africa, Department of Science and Technology, "Annual Report, 2005/06," 9, 34, 38–41.

Table 4. Selected South African Cooperative S&T Agreements	
Country	Areas of Emphasis
Belgium	Engineering, health, humanities, life sciences, natural sciences, social sciences, and technology. The following areas have been identified as possible future areas of emphasis: Antarctic research, astronomy (including Belgian access to the South African Large Telescope), environmental technology, human capacity building, information technology (possibly through FP7), nanotechnology, and manufacturing technology.
France	ICT network and water science
Germany	Biodiversity and earth science. The German database management system company SAP recently established an R&D center in Pretoria. The center specializes in technologies for emerging economies, interoperability, and end-to-end simplicity. ⁸⁶
Norway	Education, health, and oceanography
Japan	Biotechnology, information technology, and new materials
Russia	Mathematics, new materials, nuclear energy, and space
United Kingdom	Advanced manufacturing and materials, astronomy, biotechnology, climate change, and energy
Source: Republic of South Africa, Department of Science and Technology, “Annual Report, 2005/06” (report, Pretoria, DS&T, 2006), http://www.dst.gov.za/publications/annual_report.php .	

South Africa participates in the European Union's Framework Programme for Research and Technological Development, which has prioritized the following areas:

- aeronautics and space
- food safety
- genomics and biotechnology for health
- information technology
- materials and manufacturing

⁸⁶ “Research in Dialogue,” (SAP research report, 2006), http://www.sap.com/company/research/pdf/SAP_Research_Report_2006.pdf.

- nanotechnology⁸⁷

South Africa's researchers have made particular contributions in "biotechnology and genomics for health, food safety and quality, and global change and ecosystems."⁸⁸ They also have achieved recent success in information and communication technology, space, and transport.⁸⁹ In June 2005, the European–South African Science and Technology Advancement Programme formalized cooperation with the European Union's Framework Programme, encouraging the exchange of scientists among participating countries.⁹⁰

Multilaterally, South Africa cooperates with the World Bank, the United Nations, and the OECD. In the Southern Hemisphere, South Africa cooperates in the IBSA (India, Brazil, South Africa) trade alliance.⁹¹ Among African cooperative efforts, South Africa participates in the African Ministerial Conference on Science and Technology and the Southern African Development Community.⁹²

DEFENSE-RELATED R&D

South Africa's defense spending was on a dramatic downward trajectory until recently, with negative implications for defense-related R&D. Between 1990 and 2004, the South African government cut its defense budget from 13 percent of GDP to 1.5 percent of GDP.⁹³ However, defense spending as a percentage of GDP rose to 1.7 percent in 2006.⁹⁴ According to *Jane's Defence Weekly*, South Africa's defense budget was expected to rise at an annual rate of almost 9 percent for the fiscal years 2007–8 and 2008–9.⁹⁵ Most of this increase, which exceeds South Africa's expected rate of economic growth, is attributable to the acquisition of major equipment, including submarines from Germany.⁹⁶

⁸⁷ Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 33.

⁸⁸ Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 34.

⁸⁹ Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 34.

⁹⁰ Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 34.

⁹¹ Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 35.

⁹² Department of Science and Technology, Republic of South Africa, "Annual Report, 2005/06," 36–37.

⁹³ Peter Batchelor, Jacklyn Cock, and Penny McKenzie, "Conversion in South Africa in the 1990s: Defense Downsizing and Human Development Challenges," Brief no. 18, Bonn International Center for Conversion, 2000, <http://www.bicc.de/publications/briefs/brief18/content.php>.

⁹⁴ "South Africa: Military," *CIA World Factbook* (Washington, DC: CIA, 2007), <https://www.cia.gov/library/publications/the-world-factbook/geos/sf.html#Military>.

⁹⁵ Helmoed-Roemer Heitman, "South Africa Increases Defence Budget by Almost 9%," *Jane's Defence Industry*, April 1, 2007, <http://www.janes.com>.

⁹⁶ Heitman, "South Africa Increases Defence Budget by Almost 9%."

The sharp reduction in defense spending since the end of apartheid has translated into a significant reduction in defense-sector jobs. According to *Jane's Sentinel Security Assessment* in 2005, the number of defense-sector jobs declined from at least 83,000 in 1990 to 22,500 in 2003.⁹⁷ Furthermore, according to the same source, "Less visible, but much more damaging in the long term, has been the loss of skills, as engineers, scientists and technicians have migrated to other careers or other countries. The virtual disappearance of research and development funding has made it difficult to keep up with technological developments, although most of the companies continued research in the technologies critical to their main field or fields of interest."⁹⁸

The top countries of destination for emigrating scientists and engineers have been English-speaking countries, such as the United States, Canada, the United Kingdom, New Zealand, and Australia.⁹⁹ The emigration of South African defense-sector scientists and engineers, many of whom are trained in sensitive weapons programs, to various countries around the world could theoretically pose a security risk to the United States. However, the threat posed by unemployed Soviet weapons experts to the United States after the collapse of the Soviet Union, was much more severe.

Overview of Denel (Pty) Ltd

Denel (Pty) Ltd, the country's largest defense manufacturer located in the Western Cape of South Africa, is a suitable case study in South African defense technology transfer. Armscor is the state-owned defense company responsible for weapons acquisitions and sales. In 1982 Armscor established a branch responsible for arms manufacturing, Denel Ltd. Denel was incorporated in 1992, with the South African government as the sole shareholder, and is thus regarded as a public-sector defense company, known in South Africa as a *parastatal*.¹⁰⁰ In 2003 Denel ranked as the eightieth largest arms-producing company in the world, according to a

⁹⁷ "Defence Production and R&D, South Africa," *Jane's Sentinel Security Assessment*, September 5, 2005, <http://www.janes.com>.

⁹⁸ "Defence Production and R&D, South Africa."

⁹⁹ Republic of South Africa, Human Sciences Research Council, "Some Key Findings of 'Flight of the Flamingos'," January 28, 2004, <http://www.hsrb.ac.za/Factsheet-2.phtml>.

¹⁰⁰ Dan Henk, "Guns and Butter—Reframing South Africa's Arms Industry," *African Security Review* [Pretoria] 13, no. 3 (2004): 14; Madu Onuorah, "Nigeria: South African Arms Manufacturing Group Envisages New Plans for Kaduna Factory," *Guardian on Sunday* [Manchester], February 11, 2001.

survey by the Stockholm International Peace Research Institute (SIPRI).¹⁰¹ However, Denel did not appear in SIPRI's 2005 list of the world's largest arms-producing companies. In 2007 South Africa was in the process of migrating Armscor's responsibilities to separate defense procurement and R&D entities, in an effort to boost efficiency.¹⁰²

Denel's main operational divisions are aerospace and land systems. According to Denel's 2006 annual report, Denel Aerospace Systems specializes in unmanned aerial vehicles (UAVs), ground-based air defense systems, missiles and precision-guided weapon systems, and the Rooivalk attack helicopter.¹⁰³ Denel has offered to provide Turkey with the Rooivalk attack helicopter, but it is only one entrant in an international competition for Turkey's armed reconnaissance and attack helicopter program.¹⁰⁴ The aerospace division develops several UAV models, including:

- Seeker II UAV Surveillance System, which can conduct surveillance over a 250-kilometer-radius area during a period of 10 hours;
- SERAPH High-Speed Stealth Drone, designed for high-speed (Mach 0.85) low-observability, deep penetration (1,300 kilometers) reconnaissance, and strike missions;
- SKUA High-Speed Target Drone, which simulates high-speed (Mach 0.86) attack aircraft during exercises.¹⁰⁵

Another South African firm involved in UAV development is Advanced Technologies and Engineering.¹⁰⁶

Denel's land systems division is restructuring, to combine a variety of previously separate subsidiaries. The division hopes to remain a major worldwide supplier of propellants, explosives, and pyrotechnics, while also continuing the production of large- and small-caliber ammunition, and land mine clearing equipment.¹⁰⁷ One of the land systems division's products is the NTW-20 anti-materi  l rifle, recently upgraded to 20x110 HS ammunition. This rifle is described as a "large-caliber, man-portable weapon designed to neutralize long-range, high-value

¹⁰¹ "The 100 Largest Arms-Producing Companies (Excluding China), 2003," SIPRI Yearbook 2005, <http://www.sipri.org/contents/milap/milex/aprod/sipridata.html>.

¹⁰² Helmoed-Roemer Heitman, "South Africa Begins Armscor Wind Down," *Jane's Defence Weekly*, February 28, 2007, <http://www.janes.com>.

¹⁰³ Denel (Pty) Ltd, "Annual Report, 2006," 17–18, <http://www.denel.co.za/resources/AnnualReport2006.pdf>.

¹⁰⁴ Denel (Pty) Ltd, "Annual Report, 2006," 17.

¹⁰⁵ "Aerospace > UAVs," Denel, 2007, <http://www.denel.co.za/Aerospace/UAV.asp>.

¹⁰⁶ "Defence Production and R&D, South Africa."

¹⁰⁷ Denel (Pty) Ltd, "Annual Report," 2006, 19–20.

targets such as radar installations, communications equipment, parked aircraft and fuel storage facilities that are not reachable by conventional or small-caliber weapons.”¹⁰⁸ Another product under development at the land systems division is a lightweight, mobile 105-millimeter artillery system for deployment by the South African Army. The weapon is known as the Advanced Multirole Light Artillery Gun Capability, and its project name is Musuku.¹⁰⁹

Defense spending reductions have resulted in considerable financial hardship for Denel and its subsidiaries. In Denel's 2004 annual report, the 10,925-employee company was in the midst of a turnaround “from a loss-making state-owned enterprise” to “a globally-competitive, world-class defense manufacturer and a key production anchor for the South African defense industry.”¹¹⁰ However, that same year the company lost US\$59 million on revenues of US\$697 million.¹¹¹ In 2005 the *Economist* magazine observed that Denel “was on the verge of bankruptcy” and relied on exports for most (58 percent) of its revenues.¹¹² In June 2005, Denel appointed a new chief executive officer, Shaun Liebenberg, who announced that his first priority was to root out corruption at the company and his next priority was to turn around performance.¹¹³

The resulting turnaround strategy, based on the recognition that Denel is unlikely to survive as a stand-alone defense manufacturer, emphasizes joint ventures, alliances, and equity-based relationships.¹¹⁴ For example, Denel Dynamics and the Brazilian Air Force are co-developing an air-to-air missile system known as A-Darter.¹¹⁵ *Jane's Defence Industry* describes A-Darter as “a high-agility, fifth-generation missile that is intended for both close-range ‘dogfight’ engagements and longer-range intercepts.”¹¹⁶ A-Darter is compatible with Sidewinder missile stations.¹¹⁷ Another example is Denel Aviation's collaboration with Sweden's Saab AB in the creation of a company to be based in South Africa, specializing in civilian and defense

¹⁰⁸ “NTW-20 Anti-Materièl Rifle Receives an Upgrade,” Denel Insights, August 2006, http://www.denel.co.za/resources/Insights003_NTW20.pdf.

¹⁰⁹ Christopher F. Foss and Rupert Pangelley, “Denel Waits on a Contract for New 105mm Artillery System,” *International Defence Review*, May 1, 2007, <http://www.janes.com>.

¹¹⁰ Denel (Pty) Ltd, “Annual Report,” 2004, 6, <http://www.denel.co.za/resources/AnnualReport2004.pdf>.

¹¹¹ Denel (Pty) Ltd, “Annual Report,” 2004, 3.

¹¹² “Arms and the Man; South Africa's Defense Industry,” *Economist* [London], June 18, 2005.

¹¹³ Francois van Oudtshoorn, “Denel on a New Course,” *Finance Week* [Sandown, South Africa], Second Quarter 2005.

¹¹⁴ “Denel Announces Results for Year Ended 31 March 2006,” Denel, 2006, <http://www.denel.co.za/news.asp>.

¹¹⁵ “Denel Launches Missile Deal in Brazil,” Denel, 2007, <http://www.denel.co.za/news.asp>.

¹¹⁶ Helmoed-Roemer Heitman, “Denel Strikes A-Darter Deal with Brazil,” *Jane's Defence Industry*, June 1, 2007, <http://www.janes.com>.

aerostructures.¹¹⁸ In March 2007, Denel disclosed that the German company Carl Zeiss Optronics was acquiring a 70 percent stake in Denel Optronics. Denel Optronics specializes in optical and laser systems, including a popular helmet-mounted sighting and tracking system.¹¹⁹ In May 2007, Finland-based Patria announced the purchase of 264 armored, modular vehicles from Denel Land Systems. Production will begin in Finland and gradually shift to South Africa.¹²⁰

Denel has encountered serious difficulties in forming a partnership with India. In 2003 Denel agreed to sell 200 bunker-buster guns and 100,000 rounds of ammunition to India's military for about US\$3.86 million.¹²¹ In addition, India's Ordnance Factory Board, in cooperation with Denel, began construction of a US\$200 million munitions factory to supply equipment to India's factory. The factory, located on a 2,700-acre site near Rajgir in the Nalanda district of Bihar, was designed to manufacture 200,000 155-millimeter shells per year.¹²² These shells were described as "futuristic biomodular propellant charges for heavy-caliber artillery ammunition."¹²³ However, in April 2005 Denel faced bribery charges in India, putting in jeopardy its relationship with India's Ordnance Factory Board.¹²⁴ In August 2005, Indian Defense Minister Pranab Mukherjee announced the suspension of all transactions with Denel.¹²⁵ Aside from various partnerships, Denel's turnaround strategy involves:

- securing privileged access to South Africa's defense budget;
- engaging state agencies;
- fixing or exiting business lines based on commercial viability; and
- raising productivity to world-class standards.¹²⁶

¹¹⁷ Heitman, "Denel Strikes A-Darter Deal with Brazil."

¹¹⁸ "SAAB and Denel Create New International Aerostructures Player in South Africa," Denel, 2007, <http://www.denel.co.za/news.asp>.

¹¹⁹ Guy Anderson, "Denel Sells Stake in its Optronics Division to CZO," *Jane's Defence Industry*, April 1, 2007, <http://www.janes.com>.

¹²⁰ Guy Anderson, "Patria Inks South African AMV Deal with Denel," *Jane's Defence Industry*, June 1, 2007, <http://www.janes.com>.

¹²¹ Agence France Presse, "South Africa's Denel Engaged Agent to Seal India Gun Deal: Report," June 24, 2005, <http://www.lexis-nexis.com>.

¹²² Vivek Raghuvanshi, "India, South Africa to Build Munitions Plant; Factory to Produce Howitzer Shells," *Defense News*, March 4, 2002.

¹²³ "CBI Probe Casts Shadow on Denel Ordnance Factory," *Hindu* [Chennai], April 24, 2005.

¹²⁴ Khulu Phasiwe for Indo-Asian News Service, "DA Demands Probe into Bribery Allegations Against Denel," April 24, 2005; "DEFEXPO 02 Highlights India's Accelerating Acquisition Programmes," *Military Technology*, March–April 2002.

¹²⁵ "Ordnance Factory Will Not Be Shifted: Pranab," *Hindu* [Chennai], August 31, 2005.

¹²⁶ "Denel Announces Results for Year Ended 31 March 2006."

So far, Denel's financial performance offers no evidence that the turnaround strategy is working. In fact, since 2004–5, the company's financial performance has continued to deteriorate. During FY2006, Denel lost US\$190 million on revenues of US\$387 million.¹²⁷ In comparison with FY2004, when the company was already in distress, Denel's losses increased and its revenues shrank. The debt-to-equity ratio, a measure of solvency, rose to 1.4 in 2006, at least a five-year record.¹²⁸ However, in April 2007 Denel's CEO Shaun Liebenberg maintained that the company's restructuring was six months ahead of schedule and that 70 percent of its businesses would be profitable within two years.¹²⁹

Denel's financial condition is sufficiently impaired that the South African government has agreed to a recapitalization program (in the common vernacular, a bailout). Under this program, South Africa transfers significant sums to Denel to keep it in business.¹³⁰ Payments under this recapitalization program are shown in Table 5.¹³¹

Table 5. Financial Transfers from the South African Government to Denel	
Year	Amount (in millions of U.S. dollars)
2005–6	US\$283.2
2006–7	US\$80.3
2007–8	US\$132.1
Total	US\$495.6
Source: Helmoed-Roemer Heitman, "South Africa Grants Denel Fresh Turnaround Funds," <i>Jane's Defence Industry</i> , April 1, 2007, http://www.janes.com .	

The total amount, US\$495.6 million, still falls short of Denel's original request for a US\$722.1 million recapitalization.¹³²

Unless Denel gains a sound financial footing, the company is vulnerable to pressure to sell sensitive technologies to unscrupulous parties around the world. In such a scenario, the foreign policy interests of South Africa may not coincide with those of the United States.

¹²⁷ Denel (Pty) Ltd, "Annual Report," 2006, 44.

¹²⁸ Denel (Pty) Ltd, "Annual Report," 2006, 44.

¹²⁹ Helmoed-Roemer Heitman, "South Africa Grants Denel Fresh Turnaround Funds," *Jane's Defence Industry*, April 1, 2007, <http://www.janes.com>.

¹³⁰ Heitman, "South Africa Grants Denel Fresh Turnaround Funds."

¹³¹ Heitman, "South Africa Grants Denel Fresh Turnaround Funds."

¹³² Heitman, "South Africa Grants Denel Fresh Turnaround Funds."

South Africa's Former Nuclear Program

In 1974 South African Prime Minister John Vorster of the apartheid government decided to develop nuclear explosives in a secret project.¹³³ In 1976 Somchem, a Denel subsidiary specializing in energetic materials, tested a gun-type device using a natural uranium projectile. This test demonstrated the mechanical integrity of such gun-type devices. South Africa continued to work on these devices for the following 17 years, in conjunction with ongoing research into implosion-type nuclear explosives.¹³⁴ However, in 1993 during the transition from apartheid, South African President F.W. de Klerk terminated the country's nuclear weapons program and discontinued development of biological and chemical weapons. Somchem's rocket motor propellant casting pits were destroyed and sealed with concrete.¹³⁵ In taking this step, South Africa became the only country in the world ever to abandon a nuclear weapons capability.¹³⁶ In 1995 South Africa adopted the Missile Technology Control Regime (MTCR), which bans the transfer of ballistic and cruise missile technology. However, the MTCR does not ban dual-use technologies such as propellants, propulsion systems, and guidance systems.¹³⁷

Cooperation in International Nonproliferation of Weapons of Mass Destruction

South Africa's voluntary abandonment of its nuclear weapons program is unparalleled in world history.¹³⁸ Moreover, in 1993 the transitional regime of President F.W. de Klerk adopted strict policies against the procurement and proliferation of all weapons of mass destruction (WMD) and related delivery systems, via the Act on the Non-Proliferation of Weapons of Mass Destruction (Act No. 87 of 1993).¹³⁹ The same year, South Africa became a member of the Zangger Committee, which monitors the trade of nuclear-related goods and equipment.¹⁴⁰ In

¹³³ "South Africa's Nuclear Weapons Program—The Early Years," The Nuclear Weapon Archive, September 1, 2001, <http://nuclearweaponarchive.org/Safrica/SABeginning.html>.

¹³⁴ David Albright and Corey Hinderstein, *South Africa's Nuclear Weaponization Efforts: Success on a Small Scale* (Washington, DC: Institute for Science and International Security, September 13, 2001).

¹³⁵ "South Africa Profile: Somchem Rocket Motor Cast Pits," Nuclear Threat Initiative, May 2003, www.nti.org/e_research/profiles/Safrica/Missile/1601_1659.html.

¹³⁶ "South Africa's Nuclear Weapons Program—The Early Years."

¹³⁷ Martin Navias, "Towards a New South African Arms Trade Policy," *South African Defence Review* [Pretoria] 13 (1993).

¹³⁸ David Albright, "South Africa's Nuclear Weapons Program" (seminar, Institute for Science and Information Security, Washington, DC, March 14, 2001, http://web.mit.edu/ssp/seminars/wed_archives_01spring/albright.htm).

¹³⁹ Freddie van der Merwe, "Arms Control and Disarmament in South Africa after the Cold War," *Strategic Review for Southern Africa* 25, no. 1 (May 2003): 59.

¹⁴⁰ Van der Merwe, 64.

1995 South Africa joined the Nuclear Suppliers Group, ratified the Chemical Weapons Convention, and became a party to the MTCR.¹⁴¹ The purpose of the MTCR is to promote “the non-proliferation of unmanned delivery vehicles capable of delivering weapons of mass destruction.”¹⁴² In 1996 South Africa signed the Comprehensive Nuclear Test Ban Treaty, which it ratified in 1999.¹⁴³ South Africa has been a party to the Biological and Toxic Weapons Convention since 1975 and began working on related verification measures in 1994.¹⁴⁴

Arms Transfers

Arms Imports

In 2006 South Africa was the world's ninth largest arms importer, a significant jump from its position as the twentieth largest in the previous year.¹⁴⁵ SIPRI uses a special metric to indicate the volume of arms transfers, as opposed to their financial value. According to SIPRI's trend indicator value (TIV) metric, South Africa's arms imports amounted to 862 TIV in 2006, compared with top-ranked China's arms imports of 3,261 TIV in the same year.¹⁴⁶ In 2005–6 the top four arms suppliers to South Africa were Germany, the United Kingdom, Italy, and France, in rank order (see Table 6).¹⁴⁷

¹⁴¹ Van der Merwe, 64–67.

¹⁴² Missile Technology Control Regime, www.mtcr.info/english/ (accessed July 2007).

¹⁴³ Van der Merwe, 63.

¹⁴⁴ Van der Merwe, 65.

¹⁴⁵ “TIV of Arms Imports to the Top 50 Largest Importers, 2005–2006,” Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, June 29, 2007, <http://www.sipri.org/>.

¹⁴⁶ “TIV of Arms Imports to the Top 50 Largest Importers.”

¹⁴⁷ “TIV of Arms Imports to the Top 50 Largest Importers.”

Table 6. Trend Indicator Value of Arms Imports to South Africa, 2005–6		
	2005	2006
France	22	29
Germany	140	640
Italy	26	52
Netherlands	3	3
United Kingdom	124	125
United States	N/A	14
Total	315	863
Source: “TIV of Arms Imports to South Africa, 2005–06,” Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, June 29, 2007, http://www.sipri.org .		

South Africa's imports by weapon category, measured in TIV, in 2005–6 are shown in Table 7.¹⁴⁸

Table 7. Trend Indicator Value of Arms Imports to South Africa by Category, 2005–6		
	2005	2006
Aircraft	146	172
Engines	N/A	14
Missiles	27	5
Sensors	3	32
Ships	140	640
Total	316	863
Source: “TIV of Arms Imports to South Africa by Category, 2005–06,” Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, June 29, 2007, http://www.sipri.org .		

One of South Africa's most important arms acquisitions projects involves three German Type 209/1400M diesel attack submarines, which South Africa's acquisition agency Armscor ordered in 2000.¹⁴⁹ The German Submarine Consortium, consisting of Howaldtswerke-Deutsche Werft GmbH (HDW), Nordseewerke GmbH, and MAN Ferrostaal AG, jointly produced the

¹⁴⁸ “TIV of Arms Imports to the Top 50 Largest Importers.”

¹⁴⁹ “MAN Ferrostaal investiert in Südafrika,” Handelsblatt.com [Hamburg], June 11, 2007, <http://www.handelsblatt.com>.

submarines.¹⁵⁰ Each 62-foot long submarine holds a crew of 30. Equipped with modern sensors and weapons guidance systems, the vessels, each of which displaces 1,450 tons of water, modernize South Africa's navy, positioning it to patrol the strategic waters near the Cape of Good Hope.¹⁵¹

The second of the three submarines was delivered to South Africa in April 2007 as part of a very complicated transaction.¹⁵² The three submarines cost the equivalent of nearly US\$1.1 billion.¹⁵³ In exchange for this purchase, the German Submarine Consortium agreed to a package of direct investment, technology transfer, and exports at least equal to the purchase price.¹⁵⁴ MAN Ferrostaal, a member of the consortium, is in charge of this investment program, directed primarily at developing South Africa's offshore oil and gas industry.¹⁵⁵ Most of the development takes place in Saldanha Bay on South Africa's west coast and in Cape Town harbor.¹⁵⁶

Arms Exports

In 2006 South Africa was the world's sixteenth largest arms exporter, a significant jump from its position as twenty-seventh largest in the world in the previous year.¹⁵⁷ According to SIPRI's TIV metric, South Africa's arms exports amounted to 115 TIV in 2006, compared with U.S. arms exports of 7,929 TIV in the same year.¹⁵⁸ In 2006 the top three recipients of South African arms transfers were Gabon, Jordan, and Sweden (see Table 8). To help quantify the monetary value of South Africa's arms exports, *Jane's Sentinel Security Assessment* estimates that, in 2002, South Africa earned about US\$330 million from defense exports.¹⁵⁹

¹⁵⁰ "Südafrikanische Marine stellt U-Boot 'Charlotte Maxeke' in Dienst," ThyssenKrupp Marine Systems AG, March 14, 2007, <http://www.thyssenkrupp.com>.

¹⁵¹ "Südafrikanische Marine stellt U-Boot 'Charlotte Maxeke' in Dienst."

¹⁵² "Südafrikanische Marine stellt U-Boot 'Charlotte Maxeke' in Dienst."

¹⁵³ "MAN Ferrostaal investiert in Südafrika."

¹⁵⁴ "MAN Ferrostaal investiert in Südafrika."

¹⁵⁵ Helmoed-Roemer Heitman, "Ferrostaal Launches Offset Project," *Jane's Defence Weekly*, February 7, 2007, <http://www.janes.com>.

¹⁵⁶ Heitman, "Ferrostaal Launches Offset Project."

¹⁵⁷ "TIV of Arms Exports from the Top 50 Largest Exporters."

¹⁵⁸ "TIV of Arms Exports from the Top 50 Largest Exporters."

¹⁵⁹ "Defence Production and R&D, South Africa."

Table 8. Trend Indicator Value of Arms Exports from South Africa, 2005–6		
	2005	2006
Canada	N/A	8
Finland	N/A	2
Gabon	N/A	63
Jordan	N/A	23
Sweden	1	11
United Arab Emirates	N/A	4
United States	22	N/A
Zambia	N/A	3
Total	23	114
Source: “TIV of Arms Exports from South Africa by Category, 2005–06,” Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, June 29, 2007, http://www.sipri.org .		

South Africa's exports are shown for 2005–6, by weapon category and measured in TIV in Table 9.¹⁶⁰

Table 9. Trend Indicator Value of Arms Exports from South Africa by Category, 2005–6		
	2005	2006
Aircraft	N/A	67
Armored Vehicles	23	46
Missiles	N/A	2
Total	23	115
Source: “TIV of Arms Exports from South Africa by Category, 2005–06,” Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, June 29, 2007, http://www.sipri.org .		

South African Arms Export Controls

The National Committee for Control of Conventional Arms, consisting of various ministers and other members appointed by the president of South Africa, is responsible for enforcing the National Conventional Arms Control Act of 2002.¹⁶¹ Under this law, “no person is

¹⁶⁰ “TIV of Arms Exports from the Top 50 Largest Exporters.”

¹⁶¹ Van der Merwe, 69.

allowed to export, import, re-export, transport, market, trade or provide a service in conventional weapons, unless that person has a valid permit which authorizes him/her to do so.”¹⁶²

The South African government observes a defense export control system that promotes arms exports, provided that they are subject to controls based on the principles of restraint, responsibility, and *translucence*.¹⁶³ *Translucence* or *semi-transparency* is distinct from the more rigorous concept of *total transparency*. *Jane's Sentinel Security Assessment* cites a high-level official at the South African Ministry of Foreign Affairs, providing the guidelines for the export control system:

South Africa will not approve

- arms transfers to destinations under UN embargo;
- arms transfers to states that oppress their local communities or commit serious human-rights abuses if such transfers are likely to be used in the further suppression of the local population;
- arms transfers to terrorist movements;
- arms transfers to states or entities with a proven history of illegal arms trade and deviation; or
- arms transfers likely to be used against the South African military.

South Africa is unlikely to approve

- arms transfers of a lethal nature to international flashpoints and destinations of prevailing conflicts, unless there are compelling considerations to the contrary.

South Africa will closely scrutinize

- arms transfers to destinations where there are regional conflicts, taking into consideration the type of products to be exported and the likelihood that such arms transfers could detrimentally influence the balance of power in the region.

South Africa will evaluate, considering current control lists and the country of destination,

- transfers of dual-use items subject to control, under South African laws regarding nonproliferation of weapons of mass destruction.

¹⁶² Van der Merwe, 69.

¹⁶³ “Defence Production and R&D, South Africa.”

In considering whether to issue an export permit, South Africa will take into account

- the implications for the prevailing internal political situation in the receiving state;
- the implications for South Africa's relations with that state;
- the effects of the transaction in a regional context;
- the extent to which the receiving state subscribes to multilateral and international arms proliferation agreements;
- the possibility of diversion of the arms to another destination;
- the human-rights profile of the state; and
- South Africa's international undertakings and obligations.¹⁶⁴

Circumvention of Arms Export Controls

Sales of Arms to Countries in Violation of Human Rights

Although Amnesty International regards South Africa's controls as "relatively strict," Amnesty International objects to the fact that Land Systems OMC, a South African subsidiary since November 2004 of United Kingdom-based BAE Systems, has supplied Uganda and Indonesia with armored vehicles.¹⁶⁵ Amnesty International cites evidence that both countries have used these vehicles "to commit or facilitate human rights violations."¹⁶⁶ The case illustrates the use by foreign subsidiaries of arms companies to evade export controls applicable in the home country. In fact, during 2005 and 2006, when these shipments took place, the export of military vehicles from the United Kingdom to Uganda was prohibited.¹⁶⁷ Amnesty International concludes that "there is no suggestion that BAE Systems or the previous British owners necessarily knew what their subsidiary was doing. In most circumstances, current UK export control legislation places no responsibility on UK companies for the actions of their subsidiaries."¹⁶⁸

¹⁶⁴ "Defence Production and R&D, South Africa."

¹⁶⁵ "Arms Without Borders: Why a Globalised Trade Needs Global Controls," Control Arms Campaign, October 2, 2006, 19–20, http://www.controlarms.org/documents/Arms%20Without%20Borders_Final_21Sept06.pdf.

¹⁶⁶ "Arms Without Borders," 19–20.

¹⁶⁷ "Arms Without Borders," 19–20.

¹⁶⁸ "Arms Without Borders," 19–20.

Possible Bioweapons in South Africa

In the 1990s, South Africa's apartheid government conducted a secret biological and chemical weapons program known as Project Coast. The program was designed to create untraceable weapons to commit terrorism and assassination against the country's own population.¹⁶⁹ In 1993 President de Klerk terminated the Project Coast program.¹⁷⁰

Although the postapartheid government abandoned these programs and was thought to have destroyed all related stockpiles, in 2003 the *Washington Post* reported evidence that some bioweapons still existed. According to the *Washington Post*, in 2002 South African scientist Daan Goosen offered American intermediaries "an entire collection of pathogens" developed by Project Coast.¹⁷¹ Although the United States rejected the offer, concern remains that banned bioweapons may still exist in South Africa along with the danger of proliferation of these weapons.¹⁷²

CONCLUSION

South Africa aspires to follow the South Korean model of scientific innovation, emphasizing cutting-edge technologies such as biotechnology, nanotechnology, and information technology. However, in order to achieve this goal, the country must increase spending on science and technology well above the current level of less than 1 percent of GDP. In addition, South Africa will need to develop a new generation of scientists and engineers.

The retirement and emigration of South African scientists and engineers, many of whom are veterans of the country's struggling defense sector, poses some of the same dangers as the displacement of Soviet defense workers after the collapse of the Soviet Union. Hypothetically, such individuals might be tempted to participate in the transfer of sensitive defense technologies to unscrupulous parties around the world. Although South Africa's postapartheid government has abandoned the development of weapons of mass destruction, some residual expertise, and possibly even bioweapons stockpiles, may remain.

¹⁶⁹ Joby Warrick and John Mintz, "Lethal Legacy: Bioweapons for Sale: U.S. Declined Scientist's Offer of Man-Made Strains of Pathogens—Trail from South Africa to Florida Coast Highlights Dangers of Proliferation," *Washington Post*, April 22, 2003, <http://www.washingtonpost.com>.

¹⁷⁰ Van der Merwe, 64.

¹⁷¹ Warrick and Mintz.

¹⁷² Warrick and Mintz.

Furthermore, South Africa's leading defense manufacturer, Denel, has avoided bankruptcy only through a government bailout. Theoretically, a company with such a perilous financial condition might be tempted to sell sensitive technology to countries or groups opposed to U.S. interests. While South Africa has relatively strict laws governing technology transfer, the nongovernmental organization community has complained that the South African subsidiary of the UK-based BAE Systems recently shipped armored vehicles to Uganda and Indonesia, where they were used to commit human rights violations.

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In addition to the above sources, the author relied on material from South African Web sites, both corporate and governmental, and studies and commentaries by various nongovernmental organizations (NGOs). The corporate Web site of Denel (Pty) Ltd was an important source. NGOs include Amnesty International, the Institute for Science and Information Security, the Nuclear Threat Initiative, the Nuclear Weapon Archive, and the Stockholm International Peace Research Institute (SIPRI).